UNITED STATES PATENT APPLICATION

for

EXPOSED AND EMBEDDED OVERLAY STRUCTURE

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EXPOSED AND EMBEDDED OVERLAY STRUCTURE

BACKGROUND OF THE INVENTION

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1. FIELD OF THE INVENTION

The present invention relates to the field of semiconductor integrated circuit (IC) manufacturing, and more specifically, to improving the

10   design of an overlay structure.

2. DISCUSSION OF RELATED ART

Many parameters of a semiconductor device must be monitored during

15   fabrication to assure that the device will meet the specifications for performance and reliability at the end of the line. Since device fabrication may involve as many as 30 layers, it is particularly important to measure the overlay of the critical layers to each other. One critical overlay for a microprocessor is polysilicon gate layer to shallow trench isolation layer. Another critical overlay is

20   first metal layer to contact layer.

It is very challenging to measure overlay directly in a product die on a wafer. This is because of the extremely small horizontal and vertical dimensions of the features and the multiple layers of material stacked on the wafer. However, test structures representing any two layers of interest may be placed in

25   the scribelines separating the die. Then, overlay data, collected in accordance with a statistically valid sampling plan, may be analyzed using an appropriate model. The overlay may be partitioned into an orthogonal set of components which correspond to physically meaningful parameters on the step-and-scan tool that exposed the wafer. Such a feedback loop allows the step-and-scan tool to be

30   adjusted to improve overlay on wafers processed later.

As the design groundrules continue to shrink, it becomes increasingly critical to design a robust overlay structure to accommodate the process variations that can introduce considerable noise into an overlay measurement. As an example, gate layer is usually formed from polysilicon that has been

5   deposited by chemical vapor deposition (CVD) and planarized by chemical-mechanical polishing (CMP). These processes affect the thickness, roughness, and graininess of the polysilicon, thus making overlay measurement difficult.

Overlay refers to the relative placement of a subsequent layer with reference to a previous layer. Overlay is generally measured in two orthogonal

10   orientations. The orientations are usually chosen to correspond to the x-axis and the y-axis of the stage of the step-and-scan tool used to expose photoresist on the layers. For illustrative purposes in the following description, the polysilicon gate layer will be chosen as the subsequent or second layer and the shallow trench isolation layer will be chosen as the previous or first layer.

15   **Figure 1** shows a cross-sectional view of a wafer **5** in one of the two orientations after develop. The substrate **10** is formed from a semiconductor material such as silicon. Then the surface of the substrate **10** is covered with silicon oxide **30**. The outer bars **15** are formed at the first layer from shallow trenches that have been filled with a dielectric material **20**. After depositing a

20   layer of polysilicon **40** over the entire wafer, a coat of photoresist is applied. A step-and-scan tool aligns layer two (on a mask) to layer one (on the wafer) and then exposes the photoresist through the mask to form a latent image of the desired pattern from the mask in the photoresist. The inner bars **45** are formed after developing the photoresist **50**.

25   Overlay is measured after develop since, if necessary, the photoresist may be removed and re-applied for patterning again before etching is performed. First, the centerline **54** of the inner bars **45** is determined from the midpoint of the distance **52** between the centers of the inner bars. Second, the centerline **14** of the outer bars **15** is determined from the midpoint of the distance **12** between the

30   centers of the outer bars. Finally, the overlay after develop is calculated as the

difference **24** between the centerline **54** of the inner bars **45** and the centerline **14** of the outer bars **15**.

Figure 2 shows a cross-sectional view of a wafer **7** after etch in the same orientation as **Figure 1**. The top of the outer bars **15** is now exposed since the overlying polysilicon layer has been removed by the etch. The inner bars **45** are formed from polysilicon **40**.

Overlay is also measured after etch. Rework of the photoresist is no longer possible, but the etch must be monitored since the pattern in the photoresist has been transferred into the layers of material on the wafer. First, the centerline **55** of the inner bars **46** is determined from the midpoint of the distance **53** between the centers of the inner bars **46**. Second, the centerline **17** of the outer bars **15** is determined from the midpoint of the distance **13** between the centers of the outer bars **15**. Finally, the overlay after etch is calculated as the difference **25** between the centerline **55** of the inner bars **46** and the centerline **17** of the outer bars **15**.

It is preferable to measure post-develop overlay at a layer because rework of the photoresist is still possible. However, data from cross-sectioned wafers reveal that post-etch overlay is a better predictor of overlay in product devices than post-develop overlay. Overlay measurement becomes more consistent after etch because polysilicon has been removed from over the overlay structure. Consequently, it is often necessary to measure overlay after develop and again after etch in order to determine an etch offset. The etch offset is then applied to correct subsequent post-develop measurements. Unfortunately, the etch offset is not very consistent unless results are obtained by measuring the same locations on the same wafers after develop and after etch. Such a procedure is laborious and time consuming. Furthermore, the etch offset must be updated frequently since it will often fluctuate.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustration of a cross-sectional view of an overlay structure after develop (prior art).

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Figure 2 is an illustration of a cross-sectional view of an overlay structure after etch (prior art).

Figure 3 (a) is an illustration of a cross-sectional view of a novel overlay

10   structure for a transparent film after develop.

Figure 3 (b) is an illustration of a cross-sectional view of a novel overlay structure for a transparent film after etch.

15   **Figure 4 (a)** is an illustration of a cross-sectional view of a novel overlay structure for an opaque film after develop.

Figure 4 (b) is an illustration of a cross-sectional view of a novel overlay structure for an opaque film after etch.

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Figure 5 is a flowchart of a methodology to determine an offset to correct post-develop overlay measurement.

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DETAILED DESCRIPTION OF THE PRESENT INVENTION

In the following description, numerous details, such as specific materials, dimensions, and processes, are set forth in order to provide a thorough understanding of the present invention. However, one skilled in the art will realize that the invention may be practiced without these particular details. In other instances, well-known semiconductor equipment and processes have not been described in particular detail so as to avoid obscuring the present invention.

One embodiment of the present invention describes a novel post-etch overlay structure that allows the measurement of both post-etch overlay and the equivalent of post-develop overlay. The overlay structure may have multiple targets, such as three pairs of targets. Each target may be a bar, a twin bar, a trench, a twin trench, a series of holes, or a series of pillars. The various targets may differ in shape, dimension, and spacing. Another embodiment of the present invention describes a novel post-etch methodology that determines an offset to correct the measurement of post-develop overlay.

Figure 3 (a) shows a cross-sectional view of a novel overlay structure for a layer with transparent material 40, such as polysilicon, on a wafer 5a after develop of photoresist. The substrate 10 is formed from a semiconductor material such as silicon. The surface of the substrate 10 is covered with silicon oxide 30. It is desirable to form the overlay structure with product-like features. In one embodiment of the present invention, a first set 15a and a second set 15b of features, such as outer bars, are formed at an earlier layer, such as shallow trench isolation layer, from trenches that have been filled with a dielectric material 20. In some cases, the dielectric material 20 may protrude out of the top of the trenches. The first set 15a of outer bars and the second set 15b of outer bars are parallel and located near each other. The two sets of outer bars are usually coplanar.

After depositing a layer of transparent material 40, such as polysilicon, over the entire wafer at a subsequent layer, such as polysilicon gate layer,

photoresist is applied. A step-and-scan tool aligns the pattern from the subsequent layer (on a mask) to the pattern from the earlier layer (on the wafer) and then exposes the photoresist through the mask to form a latent image of the desired pattern from the mask in the photoresist. The inner bars **45a** are formed

5   after developing the photoresist **50**. Protective pads **45b** are also formed in the photoresist over the second set **15b** of outer bars. The inner bars **45a** and the protective pads **45b** are nominally parallel to the first set **15a** and the second set **15b** of outer bars.

Overlay of the novel overlay structure is initially measured after develop.

10   First, the centerline **54a** of the inner bars **45a** is determined from the midpoint of the distance **52a** between the centers of the inner bars **45a**. The centerline is the location from which the two bars are equidistant. The inner bars **45a** are nominally parallel to but located some distance away from the first set **15a** of outer bars and the second set **15b** of outer bars. Second, the centerline **14a** of the

15   first set **15a** of outer bars is determined from the midpoint of the distance **12a** between the centers of the first set **15a** of outer bars. The deviation in the location of the two centerlines is a measurement of their overlay. As a result, the overlay after develop is calculated as the difference **24a** between the centerline **54a** of the inner bars **45a** and the centerline **14a** of the first set **15a** of outer bars. The second

20   set of outer bars **15b** is not usually measured after develop since it is embedded below the transparent material **40** that is covered by the protective pads **45b** in the photoresist.

Overlay of the novel overlay structure is also measured after etch. **Figure 3 (b)** shows a cross-sectional view of a novel overlay structure for a layer with

25   transparent material **40**, such as polysilicon, on a wafer **7a** after etch. The inner bars **46a** are formed from the transparent material **40**. The first set **16a** of outer bars is now exposed or uncovered since the overlying transparent film **40** has been removed by the etch. Consequently, the first set **16a** of outer bars resembles a post-etch condition. However, the second set **16b** of outer bars is still

embedded below or covered by the transparent film **40**. Consequently, the second set **16b** of outer bars resembles a post-develop condition.

First, the centerline **55a** of the inner bars **46a** is determined from the midpoint of the distance **53a** between the centers of the inner bars **46a**. The inner

5   bars **46a** are nominally parallel to but located some distance away from the first set **16a** of outer bars and the second set **16b** of outer bars. Second, the centerline **17a** of the first set **16a** of outer bars is determined from the midpoint of the distance **13a** between the centers of the first set **16a** of outer bars. Third, the centerline **35a** of the second set **16b** of outer bars is determined from the

10   midpoint of the distance **13b** between the centers of the second set **16b** of outer bars.

Some typical dimensions are as follows. The distance **53a** between the centers of the inner bars **46a** may be about 16.0 micrometers. The distance **13a** between the centers of the first set **16a** of outer bars may be about 28.0

15   micrometers. The distance **13b** between the centers of the second set **16b** of outer bars may be about 35.0 micrometers. As product devices continue to be scaled down, the overlay structure of the present invention can be made smaller by reducing these distances to about 30 – 40 % of the values given above.

The overlay for the post-develop condition is calculated as the difference

20   **45a** between the centerline **55a** of the inner bars **46a** and the centerline **35a** of the second set **16b** of outer bars. The overlay for the post-etch condition is calculated as the difference **25a** between the centerline **55a** of the inner bars **46a** and the centerline **17a** of the first set **16a** of outer bars. The difference between the overlay for the post-etch condition and the overlay for the post-develop

25   condition is the exposed-to-embedded overlay offset. This offset can be used to correct subsequent measurements of overlay after develop.

Figure 4 (a) shows a cross-sectional view of a novel overlay structure for a layer with opaque material **140**, such as Aluminum, on a wafer **105a** after develop of photoresist. The substrate **110** is a dielectric material, such as silicon

30   oxide, that covers transistors fabricated in a semiconductor material such as

silicon. In one embodiment of the present invention, a first set **115a** of outer bars and a second set **115b** of outer bars are formed at an earlier layer, such as contact layer, from holes that have been filled with another opaque material **120**, such as Tungsten. The first set **115a** of outer bars and the second set **115b** of outer bars

5   are parallel and located near each other. They are usually coplanar as well. After depositing a layer of opaque material **140** over the entire wafer **105a** at a subsequent layer, such as first metal layer, photoresist is applied. A step-and-scan tool aligns the pattern for a subsequent layer (on a mask) to the pattern for an earlier layer (on the wafer) and then exposes the photoresist through the mask

10   to form a latent image of the desired pattern from the mask in the photoresist. The inner bars **145a** are formed after developing the photoresist **150**. Protective pads **145b** are also formed in the photoresist over the second set **115b** of outer bars.

Overlay of the novel overlay structure is initally measured after develop.

15   First, the centerline **154a** of the inner bars **145a** is determined from the midpoint of the distance **152a** between the centers of the inner bars **145a**. The inner bars **145a** are nominally parallel to but located some distance away from the first set **115a** of outer bars and the second set **115b** of outer bars. Second, the centerline **114a** of the first set **115a** of outer bars is determined from the midpoint of the

20   distance **112a** between the centers of the first set **115a** of outer bars. Finally, the overlay after develop is calculated as the difference **124a** between the centerline **154a** of the inner bars **145a** and the centerline **114a** of the first set **115a** of outer bars. The second set of outer bars **115b** is not usually measured after develop since it is embedded below the opaque material **140** which is covered by the

25   protective pads **145b** in photoresist.

Figure 4 (b) shows a cross-sectional view of a novel overlay structure for a layer with opaque material **140**, such as aluminum, on a wafer **107a** after etch. The first set **116a** of outer bars is now exposed or uncovered since the overlying opaque material **140** has been removed by the etch. The second set **116b** of outer

30   bars is still embedded below or covered by the blocks **146b** formed from the

opaque material **140**. The inner bars **146a** are formed from the opaque material **40**.

Overlay of the novel overlay structure is also measured after etch. **Figure 4 (b)** shows a cross-sectional view of a novel overlay structure for a layer with an opaque material **140**, such as aluminum, on a wafer **107a** after etch. The inner bars **146a** are formed from the opaque material **140**. The first set **116a** of outer bars is now exposed or uncovered since the overlying opaque film **140** has been removed by the etch. Consequently, the first set **116a** of outer bars resembles a post-etch condition. However, the second set **116b** of outer bars is still embedded below or covered by the opaque film **140**. Consequently, the second set **116b** of outer bars resembles a post-develop condition.

First, the centerline **155a** of the inner bars **146a** is determined from the midpoint of the distance **153a** between the centers of the inner bars **146a**. The inner bars **146a** are nominally parallel to but located some distance away from the first set **116a** of outer bars and the second set **116b** of outer bars. Second, the centerline **117a** of the first set **116a** of outer bars is determined from the midpoint of the distance **113a** between the centers of the first set **116a** of outer bars. Third, the centerline **135a** of the second set **116b** of outer bars is determined from the midpoint of the distance **113b** between the centers of the dimples **146c** located over the second set **116b** of outer bars.

The opaque material **140** prevents direct measurement of the second set **116b** of outer bars so the dimples **146c** in the opaque material **140** are measured instead. The dimples **146c** exist because the opaque material, such as Tungsten, in the holes is slightly recessed at the previous layer during the formation of the first set **116a** and the second set **116b** of outer bars. The process of chemical-mechanical polishing (CMP) performed on the opaque material **140** may cause the dimples **146c** to be slightly off-center from the second set **116b** of outer bars, but this apparent error will also occur in the product die.

The overlay for the post-develop condition is calculated as the difference **145a** between the centerline **155a** of the inner bars **146a** and the centerline **135a** of

the dimples **146c** located over the second set **116b** of outer bars. The overlay for the post-etch condition is calculated as the difference **125a** between the centerline **155a** of the inner bars **146a** and the centerline **117a** of the first set **116a** of outer bars. The difference between the overlay for the post-etch condition and the overlay for the post-develop condition is the exposed-to-embedded overlay offset. This offset can be used to correct subsequent measurements of overlay after develop.

Another embodiment of the present invention is a methodology shown in **Figure 5**. First, as shown in block **10**, the centerline **55a** (CL2) of the inner bars **46a** is determined from the midpoint of the distance **53a** between the centers of the inner bars **46a**. Second, as shown in block **20**, the centerline **17a** (CL1EX) of the exposed first set **16a** of outer bars is determined from the midpoint of the distance **13a** between the centers of the exposed first set **16a** of outer bars. Third, as shown in block **30**, the centerline **35a** (CL1EM) of the embedded second set **16b** of outer bars is determined from the midpoint of the distance **13b** between the centers of the embedded second set **16b** of outer bars. Fourth, as shown on block **43**, the post-etch exposed overlay is calculated as (CL2 – CL1EX). Fifth, as shown in block **46**, the post-etch embedded overlay is calculated as (CL2 – CL1EM). This is equivalent to the standard post-develop overlay. Sixth, as shown in block **50**, the post-etch exposed-to-embedded overlay offset is calculated as (CL1EM – CL1EX). Finally, as shown in block **60**, the post-etch exposed-to-embedded overlay offset is used to correct the post-develop overlay measurement.

Many embodiments and numerous details have been set forth above in order to provide a thorough understanding of the present invention. One skilled in the art will appreciate that many of the features in one embodiment are equally applicable to other embodiments. One skilled in the art will also appreciate the ability to make various equivalent substitutions for those specific materials, processes, dimensions, concentrations, etc. described herein. It is to be understood that the detailed description of the present invention should be taken

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as illustrative and not limiting, wherein the scope of the present invention should be determined by the claims that follow.